Journal of Science Research (2013) Vol. 12: 305-313

3-D Seismic Structural Interpretation of a Part of Aloo-Field, Southwestern Niger-Delta, Nigeria

Ologe Oluwatoyin[1], Ola-Buraimo A. Olatunji[1], Bankole Shereef A.*[1]

Abstract
Complexity of faulted subsurface configuration causing erroneous deductions in absence of well articulated interpretation approach led to a well refined 3D seismic data. Part of ALOO-Field located in offshore southwestern of Niger Delta was considered in this work. The study was aimed towards determining its subsurface structural features and retentive capacity of the reservoir for hydrocarbon. The methods employed include analysis of 3D seismic data using Petrel software; horizons and fault deductions. Seismic section were used to generate structural maps which revealed different structural styles present in the studied area. Three distinct horizons were mapped. Depth structural maps generated for all surfaces of interest show subsurface features such as the geometry of the identified horizons, W-E trending growth fault, fault echelons of which most of them dip to the east and fault assisted closures at the northwestern-central part of the studied section. The dipping pattern of the identified faults coincides with that of the growth fault which enhances trapping mechanism for the hydrocarbon. Two principal structural trapping mechanisms present are growth fault and rollover anticline which are synonymous with Niger Delta. The study has demonstrated the importance of seismic structural interpretation in understanding the structural styles present and their retentive ability for hydrocarbon.

Key words: Fault echelons, Growth faults, Rollover anticline, Seismic Sections, and Structural styles.

Introduction

Niger Delta Basin is one of the most prolific oil producing basins in the world. It is associated with complex structural features which if not well understood may hinder maximum exploitation of hydrocarbon. Therefore, it is imperative to understand detailed structural relationships between fault networks and stratigraphic stacking patterns of the area for future field development. The use of 3D seismic data to interpret oil producing fields is very important in assessing field development.

Aloo-field is located in the offshore southwestern Niger Delta within longitudes 5.4°E and 5.5°E and latitudes of 5.0°N and 5.3°N. It is a prospect in one of the southwestern concessions belonging to an active oil company in Nigeria. It covers an area of approximately 41km^2. The location map of the area is shown in Figure 1. The study area exhibits one of the classical examples of oil producing fields in Niger Delta with fault related problems in relation to hydrocarbon reservoir. Sometimes the estimate of reserves may even be dependent on structural interpretation when fluid contacts located on depth structure maps are needed as inputs in volumetric analysis [1].

The study is aimed at imaging in detail, the subsurface structures associated with new reservoirs and their retentive capacity for hydrocarbon. Majority of the traps in the Niger Delta are structurally related [2], even though stratigraphic and combined structural and stratigraphic traps are not uncommon. Therefore, our focus in this study is directed towards mapping the structural traps available and evaluating the retentive capacity of these reservoirs. The enormous cost of exploring petroleum makes it necessary to maintain a high level of precision in interpreting its subsurface structures. The main objective of seismic interpretation is

Ologe Oluwatoyin[1], Ola-Buraimo A. Olatunji[1], Bankole Shereef A.*[1]
[1]*Department of Chemical and Geological Sciences, College of Natural Sciences, Al-Hikmah University, Ilorin, Nigeria.*
**Corresponding Author: bayus4sure2@yahoo.com*

ISSN 11179333

drilling to find oil and gas. This is achieved through array of seismic profiles in order to generate coherent geologic information for optimum hydrocarbon exploration and exploitation.

Geological Setting of the Study Area

The Niger-Delta forms one of the world's major hydrocarbon provinces, and it is situated on the Gulf of Guinea on the west coast of Central Africa (Southern part of Nigeria). It covers an area between longitude 5.4 – 5.5ºE and latitude 5.0-5.3º N (Fig. 1). It is composed of an overall regressive clastic sequence, which reaches a maximum thickness of about 12km [3].

Lithostratigraphy

The Niger-Delta consists of three broad formations [4]. The oldest formation in Niger Delta is the Akata Formation characterized by dominance of hemipelagic shales. The Akata Formation is overlain by Agbada Formation which consists of paralic sequence of sand-stones and shales intercalation. The sandstone to shale ratio tends to decrease with depth. The youngest facie is the continental sediments known as Benin Formation. It overlies the Agbada Formation. It consists predominantly of fresh water bearing continental mudstones, poorly sorted sandstone and gravels (Fig. 2).

Hydrocarbon Source Rock

Several works have been carried out on the evaluation of the source rocks of Niger Delta which include; [2, 5, 6, 7, 8]. A school of thought believes that most of the hydrocarbon generated in Niger Delta were derived from both Akata and Agbada Formations [6, 7, 9, 10, 11, 12]. The Akata shale is present in large volumes beneath the Agbada Formation and is at least volumetrically sufficient to generate enough oil for a world class oil province such as Niger Delta.

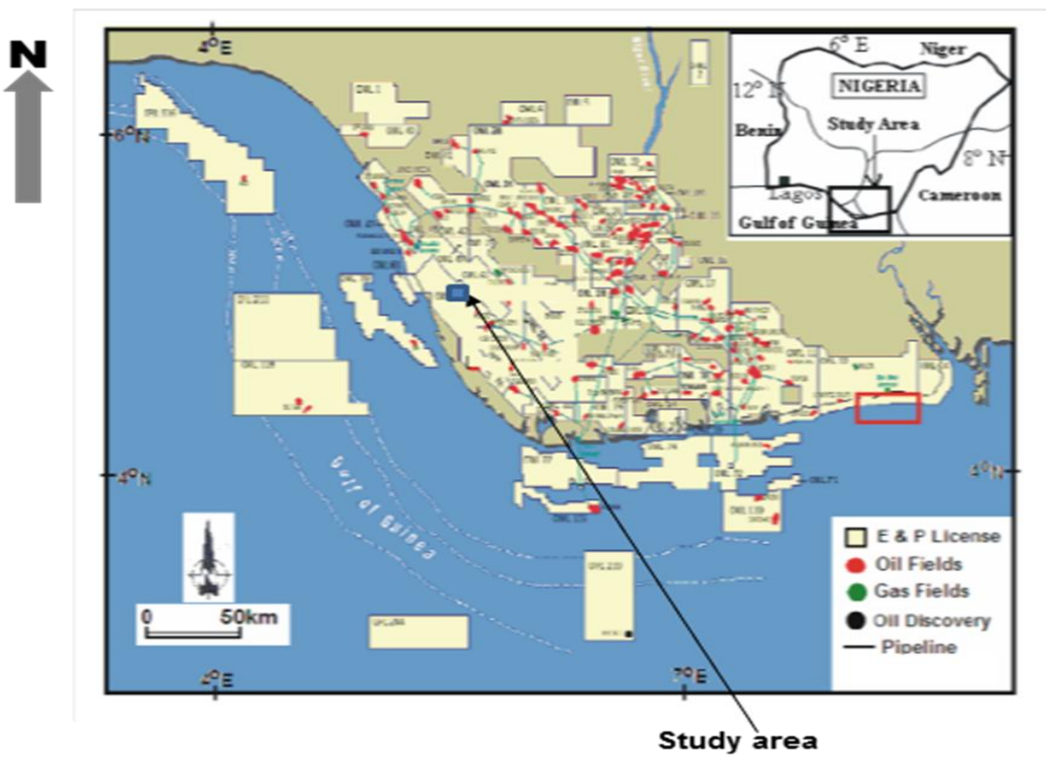

Fig. 1: Location map of Niger Delta showing the study area and the inset of map of Nigeria [13].

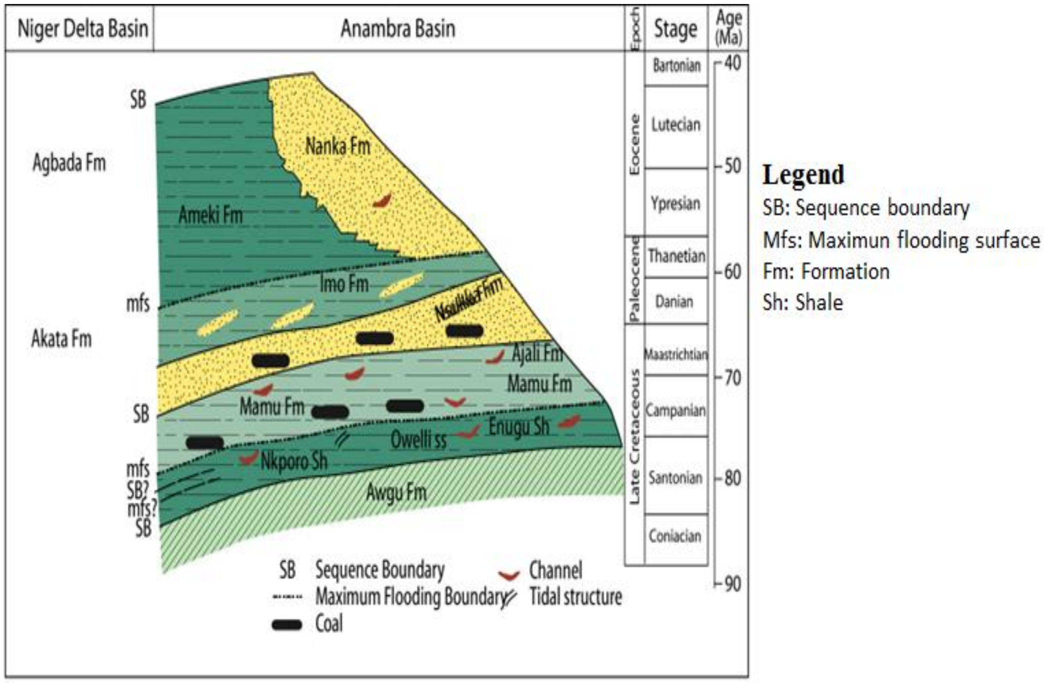

Fig. 2: Lithostratigraphic units of Niger Delta and its contemporaneous sedimentary units in the adjacent Anambra Basin [14].

Reservoir Rock

Petroleum in the Niger Delta is produced from sandstone and unconsolidated sands predominantly in the Agbada Formation. Characteristics of the reservoirs in the Agbada Formation are controlled by depositional environment and by depth of burial. Known reservoir rocks are Eocene to Pliocene in age, and are often stacked, ranging in thickness from less than 15 meters to 45 meters [3]. The thicker reservoirs represent composite bodies of stacked channels [2]. Based on reservoir geometry and quality, different reservoir types present are point bars of distributary channels and coastal barrier bars intermittently cut by sand-filled channels [15]. The primary reservoirs in Niger Delta dated Miocene age were described to be paralic sandstones with about 40% porosity, 2 darcy permeability, and with a thickness of 100 meters [2]. The lateral variation in reservoir thickness is strongly controlled by growth fault while the reservoir thickens towards the fault within the down-thrown block [9].

Traps and Seals

Most known traps in Niger Delta fields are structural although stratigraphic traps are not uncommon [14]. The structural traps were developed during synsedimentary deformation of the Agbada paralic sequence [3,10]. Structural complexity increases from the north (earlier formed depobelts) to the south (later formed depobelts) in response to increasing instability of the under-compacted, over-pressured shale [2] described a variety of structural trapping elements, including those associated with simple rollover structures; sand filled channels, multiple growth faults, antithetic faults and collapsed crest structures. The primary seal in the Niger Delta is the interbedded shale within the Agbada Formation. Recent studies show that hydrocarbons are trapped by roll over anticlines and fault closures [16].

Methodology

In this research, 3-D seismic data was used. The technique involves interpretation of the data using PETREL software. The seismic data were checked for quality to prevent interpretation pitfalls such as structural misinterpretation. The seismic section was then calibrated based on horizons of interest. Horizons were tracked manually, faults were then identified and marked on the section. Interpretation procedure of the main structural framework can be summarized as follows:

(1) Identification of main seismic reflectors from the 3D seismic data.
(2) Manual picking of horizons at this spot on inlines and crosslines whereby a combination of volume auto tracking and interpolation were then used to infill the analysis.
(3) Identification of faults networks on the seismic section was also mapped out.

A contouring interval of 20 m was used while the minimum and maximum contour were 2615 m to 3185 m, 2926 m to 3749 m, and 2956 m to 3932 m for horizons D7.5, E1.0 and E4.2 respectively. Structural maps were generated and integrate or interpretation. Structural contour maps generated were employed in monitoring reservoir distribution and identification of hydrocarbon prospect away from the known productive zones. Horizon and fault interpretation were then carried out.

Results and Discussions

The 3D seismic data was interpreted on an interactive workstation. The three key horizons (E4.2, E1.0 and D7.5) were interpreted and mapped using their seismic continuity. The continuity of the fault segments and their assignment were rigorously checked on the seismic sections (Fig. 3). Three horizons of different characteristics were mapped and these include; horizon E1.0 is characterized by low-to-high or variable amplitude reflections, with poor-to-low continuity. In some places, it is disturbed by some truncations which are more of fault related than lithologic heterogeneity. The second horizon was tagged D7.5 and it is characterized by high amplitude moderate-to-good continuity ref-lections, mostly appearing parallel-to- sub parallel. Horizon E4.2 which is the third horizon was characterized by high amplitude with moderate-to-good continuity reflections, mostly disturbed by some truncations.

The seismic data analysis revealed presence of growth faults labelled A and B on the seismic section (Fig. 3). Both faults A and B are the major structure building faults, which correspond to the growth fault in the area. Fault population is characterized by mostly east-west trending normal faults that are dipping towards the south-west, parallel to the main boundary faults (A and B). In the north, fault population is characterized mostly by north-south trend normal faults. This is in response to the main boundary fault to the west of the Aloo-field which trends north-south direction. The identified growth faults (A and B) are significantly responsible for trapping of hydrocarbon. The trapping configurations of the faults along with the embedding shale are presumed to be responsible for the creation of multiple reservoir compartments of hydrocarbon bearing formations that are witnessed from one horizon to another. The vertical displacements of the growth faults show that the amount of throw on both sides of the faults are small and varied from line to line in the seismic survey but increases in the northern part of the field for all the horizons considered (Fig. 4).

ISSN 11179333

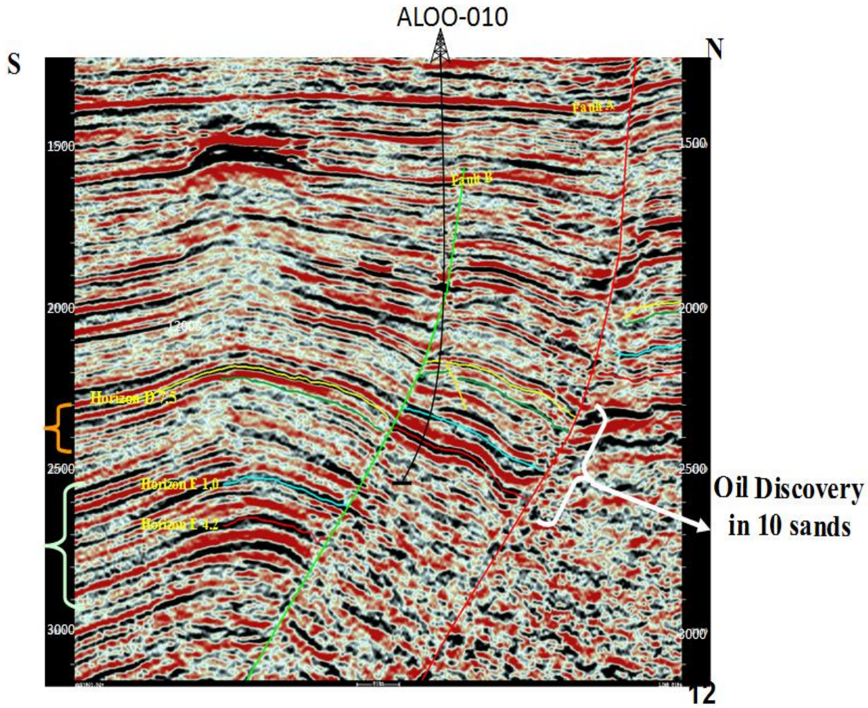

Fig. 3: Seismic section showing the picked horizons and the associated fault.

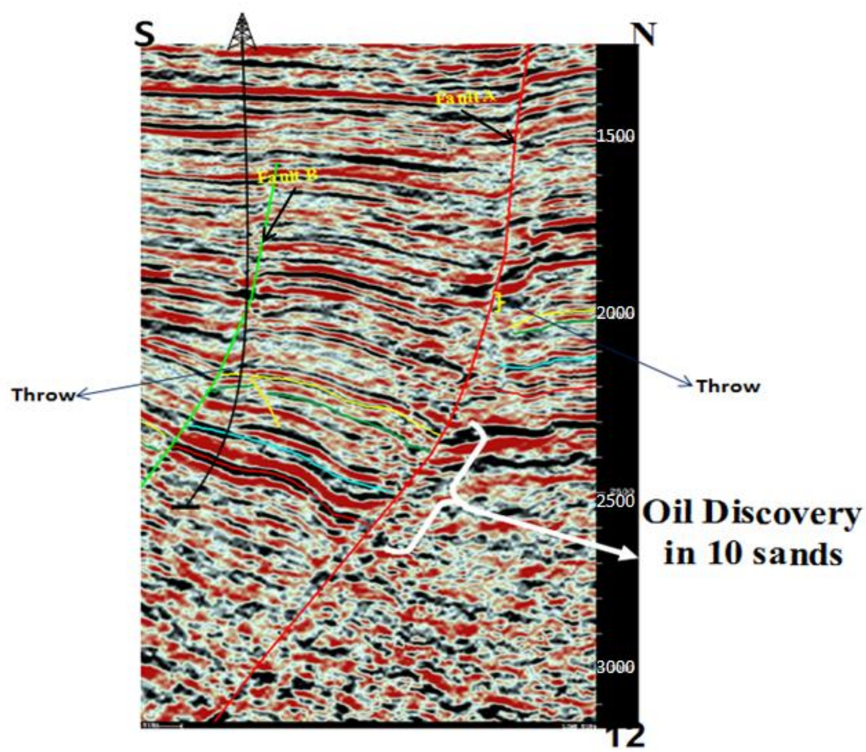

Fig. 4: Seismic section showing the various degree of throw increasing from south to north.

Depth structural map of horizon E1.0 is presented in Figure 5. The contoured map has values ranging from 2926.12 m in the north to 3749.1 m in the southeast. Structural highs are observed at northwest-centre of the field. This is represented by closed structure between the interval of 3334.6 m to 3317.5 m as can be seen on the map (Fig. 5). This area forms a good trapping system thereby increasing retentive capacity for hydrocarbon. Factors such as; low throw index, increased convex curvature, grouting, wedging and excellent shale seal for the hydrocarbon trapping in the area are responsible for the excellent retentive capacity. The oil-gas contact (OGC) is delineated at depth of 3221.8 m and the oil-water contact (OWC) is established at depth of 3243.1 m (Fig. 5).

Structural highs can also be seen in the north but no hydrocarbon accumulation has been linked to it due to the presence of crestal fault that could lead to secondary migration of hydrocarbon into another reservoir. Figure 6 is the depth structural map for horizon D7.5. The contoured interval value ranges from to 2615.2 m in the north to 3185.2m in the east. Structural highs were observed in the northwestern part of the horizon where gas has been identified. The structural highs serve as good traps for the hydrocarbon accumulation. The oil-water contact (OWC) is located at depth of about 2706.7m. In the northwestern section between the contour interval of 1859.3 m and 2651.8 m, closed structures were seen. Since the contour values in the northwestern section for this interval are very low compared to the adjacent contours, thus, the area is suggested to be structurally high Fig. 6.

The closed structures represent anticlinal forms that can serve as good hydrocarbon traps. In Figure 7, the depth structural map for horizon E4.2 is presented. The contoured map value ranges from 2956.6 m in the east to 3932 m in the north. Structural highs were observed in the northwestern part of the field where gas has been identified. The structural highs represent good trapping system for the hydrocarbon in the analysed horizon. The gas-oil contact (GOC) has been traced out to the depth of 3386.4m. Also, in the northwestern sector between the contour intervals of 3078.5 m and 3901.5 m, closed structures were noticed. Since the contour values are very low compared to the adjacent contours, this area has also been zoned as a structural high. The closed structures indicate anticlinal structures. These structures also serve as good trapping mechanism for hydrocarbon accumulation found within. The oil-water contact (OWC) is situated at depth 3394 m. The structure in the northern part of the field covers an area of about 9.5 km^2 while, the one at the centre of the field spans an area of about 10.19 km^2. These structures can serve as good traps for the hydrocarbon reservoirs because they can impede both vertical and lateral migration of fluids, with the embedded shale serving as the seal. The extensive lateral area covered by the structural highs combined with fairly thick reservoirs mapped could suggest occurrence of economic accumulation of hydrocarbon.

ISSN 11179333

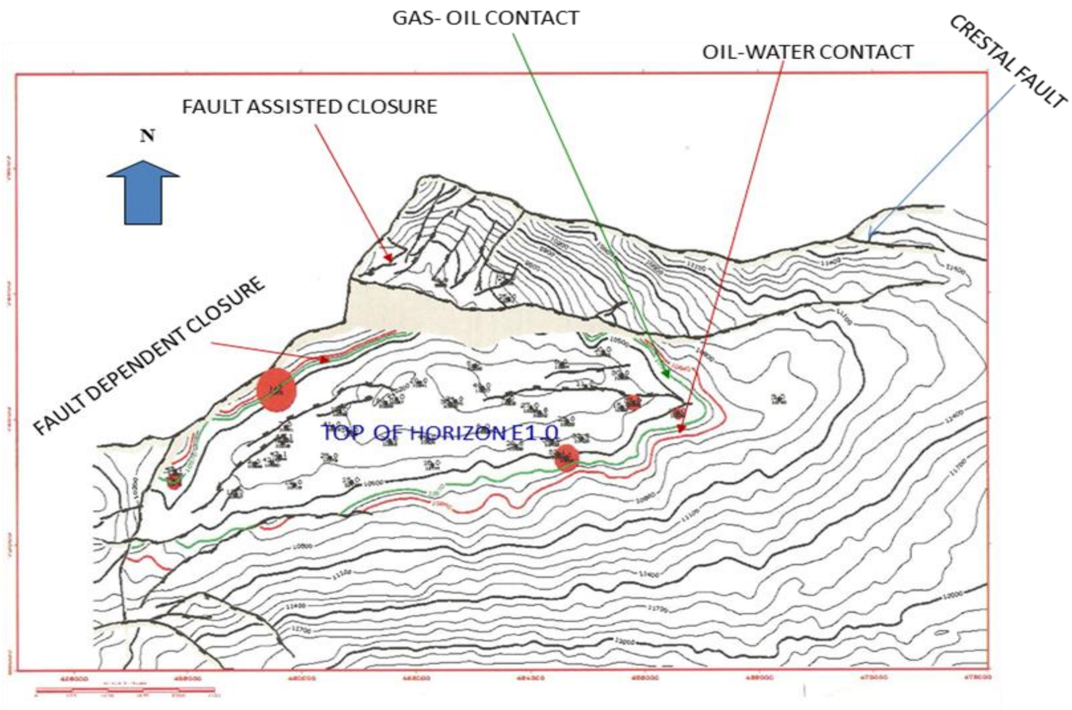

Fig. 5: Depth structural map of horizon E 1.0.

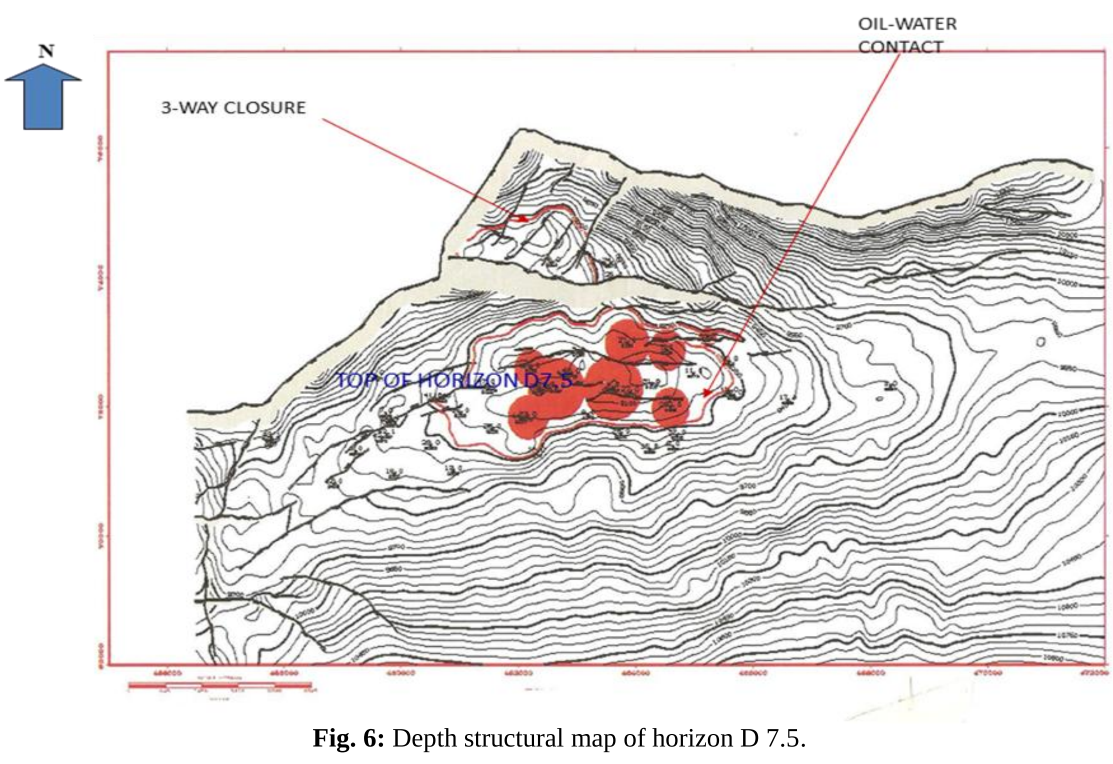

Fig. 6: Depth structural map of horizon D 7.5.

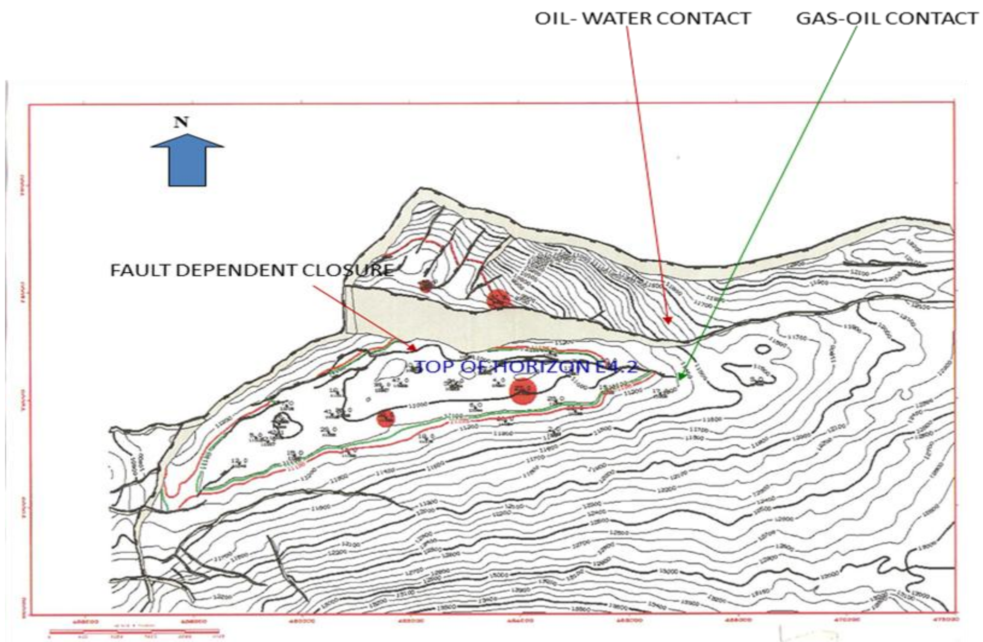

Fig. 7: Depth structural map of horizon E 4.2.

Conclusion

3D seismic structural interpretation was carried out on part of Aloo-Oil Field through the analysis of three selected horizons which include; EI.0, E4.2 and D7.5. Main structural features of the area are growth faults, anticlinal structures, rollover anticlines and crestal faults. The growth faults trend W-E and dip towards the east, while the northern part is defined by fault population trending N-S which are responsible for high retentive capacity of the reservoirs and the hydro-carbon trapping mechanism in the studied area. Both gas and oil are present in the area. Gas-Oil contact (GOC) and Oil-Water contact (OWC) were established for horizons E1.0 and E4.2; while only Oil-Water contact (OWC) was delineated at horizon D7.5.

The degree of fault throws tends to improve from south to north thereby increasing retentive petroleum capacity in the north than in the south. Also, closed structures are present in all the analysed horizons whereby the associated structural highs suggest good hydrocarbon trapping system. However, crestal faults present are incapable of holding hydrocarbon which may be responsible for secondary migration in the area. Therefore, large area covered by structural highs, growth faults, rollover anticlines and fair reservoir thickness are suggested to be the controlling factors responsible for economic hydrocarbon accumulation in the studied area.

References

(1) Jon, G., Richard, S. 2004. *Petroleum Geoscience*. USA: Blackwell Publishing. 112.

(2) Doust, H., Omatsola, E. 1990. Niger Delta. In: Edwads, J.D., Santogrossi, P.A., eds. Divergent/passive Margin Basins. AAPG Memoir 48, Tulsa: *American Association of Petroleum Geologists*. 239-248.

(3) Evamy, B.D., Haremboure, J., Kamerling, P., Molloy, F.A. and Rowlands, P. H. 1978. Hydrocarbon habitat of Tertiary Niger Delta. *American Association of Petroleum Geologists Bulletin*. 62: 1-39.

(4) Short, K.C., Stauble, A.J. 1967. Outline of Geology of Niger Delta. *American Association of Petroleum Geologists Bulletin*. 761-768.

(5) Ekweozor, C.M., Okogun, J.I., Ekong, D.E.U. and Maxwell, J.R. 1979. Preliminary organic geochemical studies of samples from the Niger Delta, Nigeria, Part 1, analysis of crude oils for triterpanes. *Chemical Geology*. 27: 11-28.
(6) Ekweozor, C.M., Okoye, N.V. 1980. Petroleum source-bed evaluation of Tertiary Niger Delta, *American Association of Petroleum Geologists Bulletin*. 64: 1251-1259.
(7) Lambert-Aikhionbare, D.O. and Ibe, A.C. 1984. Petroleum source-bed evaluation of the Tertiary Niger Delta, discussion, American Association of Petroleum Geologists Bulletin, 68: 387-394.
(8) Bustin, R.M. 1988. Sedimentology and characteristics of dispersed organic matter in Tertiary Niger Delta: origin of source rocks in a deltaic environment, *American Association of Petroleum Geologists Bulletin*. 72, 277-298.
(9) Weber, K.J. and Daukoru, E.M. 1975. Petroleum geology of the Niger Delta. Proceedings of the Ninth World Petroleum Congress, Geology, 2, London: 210-221.
(10) Stacher, P. 1995. Present understanding of the Niger Delta hydrocarbon habitat. In Oti, M.N., Postma, G., eds. Geology of Deltas, Rotterdam A.A, Balkema: 57-267.
(11) Frost, B.R. 1997. A Cretaceous Niger Delta Petroleum System: Extended abstracts, Petroleum Systems of the South Atlantic Margin, AAPG/ABGP Hedberg Research Symposium, November 16-19, Rio de Janeiro, Brazil.
(12) Haack, R.C., Sundararaman, P. and Dahl, J. 1997. Niger Delta petroleum System: Extended abstracts, Petroleum Systems of the South Atlantic Margin, AAPG/ABGP Hedberg Research Symposium, November 16-19, Rio de Janeiro, Brazil.
(13) Stacher, P., Ozunmba, B.M. and Ehoche, P. 1993. Revised Chronostratigraphic and sequence stratigraphic chart, Niger Delta, Nigeria. SPDC Exploration report no 93-01.
(14) Reijers, T.J.A., Petters, S.W. and Nwajide, C.S. 1997. The Niger Delta Basin. In: Selley R C, ed. African Basins-Sedimentary Basin of the World, Amsterdam: Elsevier Science. 151-172.
(15) Kulke, H. 1995. Regional petroleum geology of the world. Part II: Africa, America, Australia and Antarctica: Berlin: Gebrüder Borntraeger. 143-172.
(16) Aizebeokhai, A.P. and Olayinka, I. 2011. Structural and stratigraphic mapping of Emi field, offshore Niger Delta. *Journal of Geology and Mining Research*. 3(2), 25-38.